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DESCRIPTION OF A SOLUBLE POISON (BORIC ACID) CONTROL LOOP TO BE INSTALLED IN THE ISPRA-2 REACTOR

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ABSTRACT

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A loop for reactor control research using the circulation of an aqueous solution of boric acid is described. Such a loop to be installed in the ISPRA-2 reactor, was designed in collaboration with the Gruppo Esercizio Reattori di Ispra and is part of the C.A.R.L.A. program. Installation by the end of the current year is anticipated.

Author

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The loop is intended for research concerning the possibility of controlling the neutron flux of the ISPRA-2 reactor by circulation of an aqueous solution of boric acid.

In particular, it is of interest to examine the dynamic characteristics of such a type of control, which is distinguished from the customary pressure control method; the examination of the chemical aspects of the problem (separation of boric acid from the solution, absorption of boric acid by loop materials, and

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behavior of the solution when subjected to irradiation) is set aside for separate investigation in view of the limited space available in the vicinity of the reactor.

The loop is open, and it does not include any separation apparatus (e.g., ion exchanger type) for recovery of the boric acid from the solution to restore it to the cycle. The control is effected by causing the aqueous solution of boric acid to circulate within the pile and by injecting the saturated solution of boric acid into the water loop to effect a change of reactivity.

It is advisable that the quantity of injection be a relatively small fraction (less than 20 percent of the principal amount in circulation) in order: /5

1. not to disturb the hydraulic system unduly, and in particular the in-pile quantity. Consideration is also given to the possibility of installing an automatic dosage control system.
2. to avoid occurrence within the pile of abrupt changes of concentration which would subject the reactor to sudden fluctuations of reactivity. The flow regulating system would comprise a suitable controller of the (1 - exp (-sT))/S type which would have the specific assignment of leveling off the reactivity steps; but, in any case, it is preferable to reduce discontinuities of this kind to a minimum.

The mean rate of reactivity M changes (the mean being established for a time equal to loop time T) is proportional to:

$$\frac{K_R}{T}\left(\frac{W_i}{W}\right)$$

where K_R = reactivity value of the in-pile section (percent),

T = loop time (sec),

W_i = amount of injection, and

W = principal amount.

Since it is not advisable to have K_R exceed 500 to 600 percent for reasons of safety, and since, on the other hand, it is desirable, no matter what has been said previously, to have $W_i/W \leq 0.2$, it follows that to have a mean rate of variation of reactivity sufficient for control ($\sim$5 percent/sec), it is necessary to limit loop time T to a value on the order of 4 sec. /6

Furthermore, allowance must be made for the fact that M is a function of the concentration of the circulating solution (C_S), either because the effect of an injection of water or of saturated solution is different, depending upon C_S (it is proportional to $C_P - C_S$ in case of injection of saturated solution in concentration C_P, or proportional to C_S in case of water injection) or because the reactivity control of the solution is not proportional to C_S, but increases exponentially with C_S and attains an asymptotic value at a concentration slightly below saturation.

To limit such fluctuations of M and to reduce its asymmetry in the two cases of water or poison solution injection, it is suitable to limit the range of variation of C_S to 5-20 grams/liter of boric acid. Correspondingly, there is a variation of reactivity equal to about 46 percent of maximum reactivity relative to the saturated solution (50 g/liter). In these circumstances, it is suitable that there be a ratio of about 2 between the quantity of water injection and saturated solution injection.

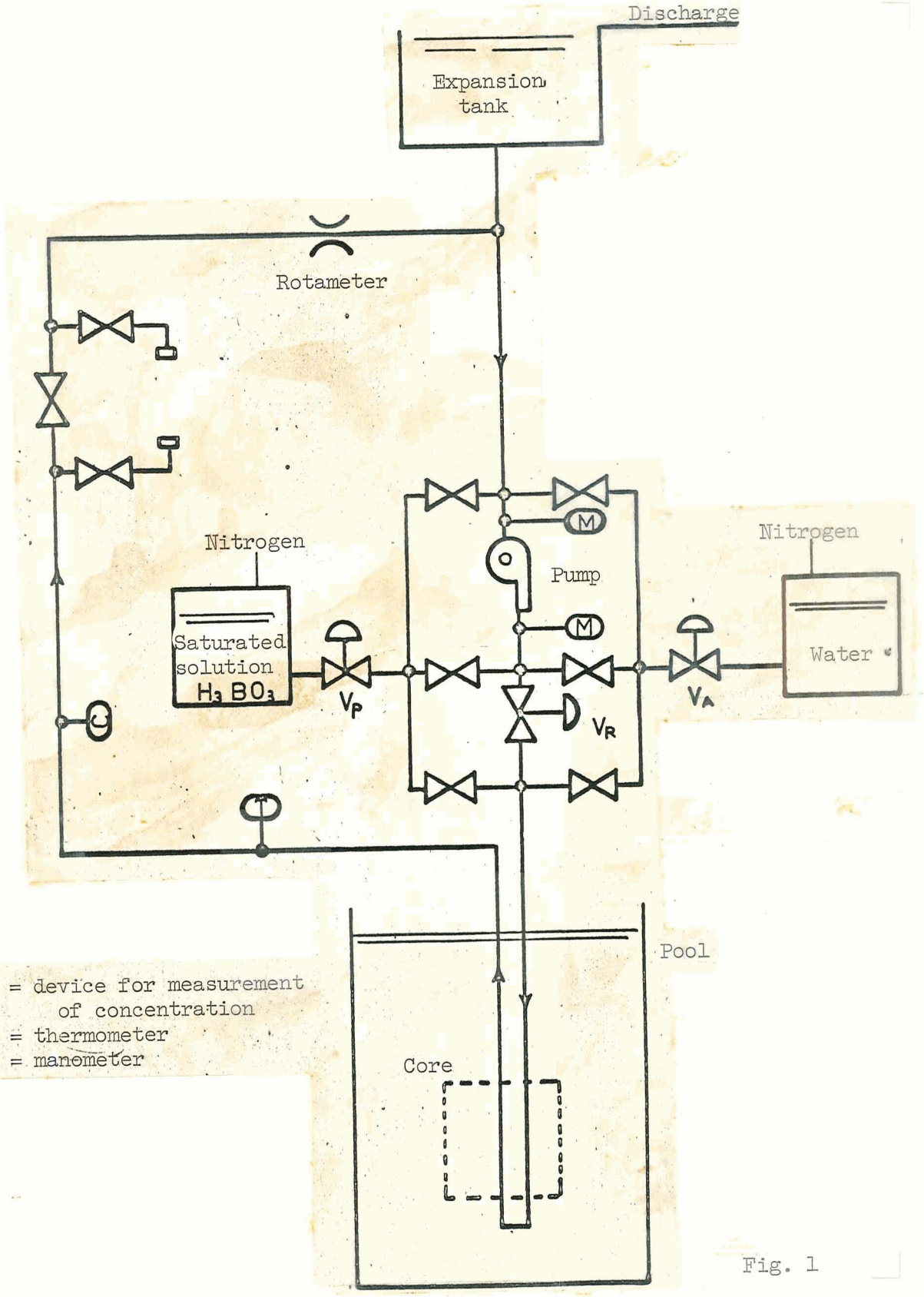
A preliminary study carried out on the analog computer has shown that in /7
these conditions the dynamic behavior of the system is satisfactory, provided that regulating valves, and not the on-off type, are used for control. The possibility of using volumetric pumps for injection has been rejected because the dimensions of such pumps would be relatively great, with only intermittent operation, for rather short periods. It is preferable, therefore, to use control valves supplied from tanks (water and saturated solution respectively) held at constant pressure.

A tentative diagram of the hydraulic loop is presented in fig. 1.

The expansion tank, connected to the loop at the point near the pump suction head, serves to maintain the pressure of the loop at a constant level. It must have an adequate section ($\sim$0.5 m^2) in order to limit pressure variations in the hydraulic loop that would result from the injection of water or of saturated solution. An overflow is provided which discharges into a collecting tank. A free water level (expansion tank) at a height of several meters above the point of connection of the hydraulic loop seems to be sufficient.

Taking into account the depth of the pool in which the core of the ISPRA-2 /8
is installed, it can be seen that the total length of the hydraulic loop should be on the order of 20 m, and, because a loop time of 4 sec is desired, the resulting rate of circulation is to be $\sim$5 m/sec.

The tubes in the out-of-pile portions have an internal diameter of $\sim$30 mm. The resulting quantity is therefore approximately 4 liters/sec, and distributed



C = device for measurement of concentration
T = thermometer
M = manometer

Fig. 1

head loss is about 2 atm. To compensate for localized head loss, and losses of regulating valve V_R, a pump with an approximately 80 m head has been selected. Selection of a tube of lesser diameter, with equal circulation rate, would occasion a much smaller flow and greater head losses, and would require a centrifugal multicell pump with many impellers. In any case, a centrifugal pump seems preferable to a volumetric one on the basis of cost and characteristic head form. The entire loop, including valves and pump, is made of stainless steel to avoid corrosion by the boric acid and absorption of the boric acid by loop materials.

Upon injection, the quantity tends to increase in the in-pile section, while it tends to decrease in the portion between the expansion tank and the point of injection (the sum of the above-mentioned two variations should equal the quantity injected). To reduce to a minimum the variations of quantity in the in-pile section, it is advisable that the hydraulic resistance of the portion between the expansion tank and the point of injection be low with respect to that of the entire loop, so that a variation of quantity in this section will have an insignificant effect upon the total head loss. The portion between the expansion tank and the point of injection should be relatively short, however, in a manner compatible with the geometry of the entire installation. /9

The possibility of effecting the injection at various locations along the loop is provided, specifically:

1. downstream of valve V_R, to minimize the transit time to the core (which improves the stability and the responsiveness of the control system).

2. upstream from the regulating valve, to reduce hydraulic resistance of the loop portion between the expansion tank and the point of injection.
3. upstream from the circulation pump, to reduce the resistance still more, and to cause the pump to operate in quantitative conditions that are practically constant.

Injection branches are provided in parallel and furnished with cutoff /10
valves. Because water or saturated solution tends to stagnate in such branches, it is suitable to use separate branches for the two injection loops. Obviously in an installation of a specific type in which there would no longer be such a need for versatility, the injection loops could be substantially simplified. For such loops 1/2" tubes are adequate.

As far as the in-pile portion is concerned, it was decided, for the sake of simplicity, to use a stainless steel U tube in construction (rather than aluminum, for instance) because activation of steel at low power levels (~100 watts), for which the loop is intended, should not be troublesome.

As to the reactivity absorbed by this tube, a rough estimate can be obtained by comparing reactivity absorbed by a tube full of boric acid solution (which was measured directly on the ISPRA-2 reactor). Assuming for stainless steel a mean microscopic absorption cross section of 3 barns/atom and a mean atomic weight of 56 (as against 750 barns/atom of boron, which has an atomic weight of~11), it is seen that 2.5 kg of stainless steel is approximately equal to 2 g boron. Because in the experimental section approximately 10 to 15 g /11
boron are contained in a saturated state, absorption by the steel jacket must be slight in comparison to that of boron (result on the order of 100 percent).

In any case, because allowance must be made for the shielding effect of steel in comparison to that of the solution within (damping of neutron flux within the section), it is well to measure directly the absorbed reactivity of a stainless steel U tube of aqueous solution of boric acid at various concentrations.

As for the volume of the in-pile absorbing section and its position in the core, these must be such that the absorbed reactivity for a boric acid concentration of 20 g/liter will be~400 percent (which corresponds to a maximum saturated solution-absorbed reactivity of a little more than 600 percent) or equal to excess reactivity ΔK available in the reactor, whenever ΔK is less than 400 percent.

Arrangements must make allowance for the fact that it is not suitable to have the diameter of the in-pile section less than that of the remaining portions of the loop in order to avoid having the solution flow rate in the in-pile section become too high.

Both the dimensions and the location of the in-pile section will be determined by a direct measurement of absorbed reactivity, and, in any case, it is wise to anticipate the possibility of being able to remove the in-pile section in the core with a certain degree of ease. If the reactivity absorption by the stainless steel were to become too great, it would be necessary to use an aluminum section. /12

The tanks upstream of the two injection valves must have a volume of ~200 liters, to permit the carrying out of a control experiment over a certain period (~1 hour). Such tanks must be maintained at a pressure a good deal higher than the maximum pressure at the point of injection (about equal to the control pressure of the pump) using a nitrogen atmosphere derived from a gas bottle. The pressure in such tanks should be on the order of 20 atm, so that a possible variation of this pressure due to imprecision of the expander connected to the gas bottle would not notably affect the injection quantity.

In order to be able to vary the length of the return branch of the loop, it is possible to insert into it a section of suitable dimensions that permits both a simple slowing of transit and a permanent lengthening of mixing time.

The three valves V_R, V_A, V_P are pneumatically controlled and supplied from /13 the same pneumatic line that was provided for the experiment with the reactivity oscillator. The possibility of associating valve V_R with a throughput meter is provided for, whereby there would be an automatic control of the quantity in the in-pile section. Loop instrumentation further includes 3 manometers, a thermometer and a device for measuring the boric acid concentration (conductivity cell type) which furnishes a base signal through the control apparatus.

The hydraulic loop must be dimensioned to meet the various requirements described above, in particular the requirement that its length must be minimal (especially the branch between the expansion tank and the in-pile section). Given the pressure of the two tanks, the entire hydraulic loop will be designed

for an operating pressure of 20 atm. Filling and emptying the loop must be provided for, as well as means for moving and substitution of the in-pile section.

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